PB-231 598

OPERATIONAL CONTROL PROCEDURES FOR THE ACTIVATED SLUDGE PROCESS

PART IIIA. CALCULATION PROCEDURES

NATIONAL FIELD INVESTIGATIONS CENTER

DECEMBER 1973

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA-330/9-74-001-c	2.	PB 231 598

4. Title and Subtitle
Operational control procedures for the activated sludge process, part IIIA - calculation procedures.

5. Report Date
December 1973.

6.

7. Author(s)

8. Performing Organization Rept. No.
EPA-330/9-74-001-c

9. Performing Organization Name and Address
U. S. Environmental Protection Agency, Office of Enforcement and General Counsel, National Field Investigations Center, Cincinnati, Ohio

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstracts

Calculation procedures used by the Waste Treatment of the National Field Investigations Center - Cincinnati during technical assistance projects are described in this Part III of the Operational Control Procedures for the Activated Sludge Process. The suggested types and frequency of observations and control tests have been described in Parts I and II. Essential flow data, such as waste water flow into the aeration tanks, return sludge flow, excess sludge wasted from the process, etc., are determined from the plant flow meters at each test period. Sludge and process characteristics, such as mixed liquor and return sludge concentrations, settled sludge volume, depth of sludge blanker in the final clarifier, etc., are determined by the control tests that have been described in Part II CONTROL TESTS.

17. Key Words and Document Analysis. 17a. Descriptors

calculation procedures
activated sludge process
control procedures

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Available from NTIS	UNCLASSIFIED	56
	20. Security Class (This Page) UNCLASSIFIED	22. Price $3.75

EQUIVALENTS USED FOR ACTIVATED SLUDGE CALCULATIONS

ft	x	0.3048	=	m
inches	x	2.540	=	cm
m	x	3.28083	=	ft
m	x	39.37	=	in
sq ft	x	0.0929	=	sq m
sq m	x	10.7639	=	sq ft
cu ft	x	28.3170	=	liter
cu ft	x	0.028317	=	cu m
cu ft	x	7.48052	=	gal
cu m	x	1000.0	=	liter
cu m	x	35.3145	=	cu ft
cu m	x	264.179	=	gal
gal	x	3.785	=	liter
gal	x	0.003785	=	cu m
liter	x	0.26417	=	gal
mgd	x	3785	=	cu m/day
cu m/day	x	0.000264	=	mgd
gpd/sq ft	x	0.0408	=	cu m/day/sq m
cu m/day/sq m	x	24.51	=	gpd/sq ft
lb	x	0.453592	=	kg
lb	x	453.592	=	g
kg	x	2.20462	=	lb
kg	x	1000.0	=	g
lbs/1000 cu ft	x	16.0	=	g/cu m
g/cu m	x	0.0625	=	lbs/1000 cu ft
cu ft (H_2O)	x	62.4	=	lb (H_2O)
gal (H_2O)	x	8.345	=	lb (H_2O)
liter (H_2O)	x	1.000	=	kg (H_2O)

lb/day = mgd x mg/l x 8.345
kg/day = cu m/day x mg/l /1000

lb = English SLU x (WCR*/1198)
kg = Metric SLU x (WCR/10)

English SLU = Metric SLU x 264.2
Metric SLU = English SLU x 0.003785

*WCR = sludge weight (mg/l)/centrifuged concentration (%)

NATIONAL FIELD INVESTIGATIONS CENTER - CINCINNATI

OPERATIONAL CONTROL PROCEDURES
FOR THE
ACTIVATED SLUDGE PROCESS

PART IIIA

CALCULATION PROCEDURES

by

Alfred W. West, P.E.
Chief, Waste Treatment Branch

DECEMBER 1973

1-A

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF ENFORCEMENT AND GENERAL COUNSEL

FOREWORD

The Waste Treatment Branch of the National Field Investigations Center - Cincinnati is developing a series of pamphlets describing Operational Control Procedures for the Activated Sludge Process. This series will include Part I OBSERVATIONS, Part II CONTROL TESTS, Part III CALCULATION PROCEDURES, Part IV SLUDGE QUALITY, Part V PROCESS CONTROL, and an APPENDIX. Each of these individual parts will be released for distribution as soon as it is completed, though not necessarily in numerical order. The original five-part series may then be expanded to include case histories and refined process evaluation and control techniques.

This pamphlet has been developed as a reference for Activated Sludge Plant Control lectures I have presented at training sessions, symposia, and workshops. It is based on my personal conclusions reached while directing the operation of dozens of different activated sludge plants. This pamphlet is not necessarily an expression of Environmental Protection Agency policy or requirements.

The mention of trade names or commercial products in this pamphlet is for illustrative purposes and does not constitute endorsement or recommendation for use by the Environmental Protection Agency.

Alfred W. West

TABLE OF CONTENTS

	PAGE NO.
DATA SOURCES AND TEXT ORGANIZATION	1
ACTIVATED SLUDGE CHARACTERISTICS	4
Activated Sludge Concentrations - ATC & RSC	4
Sludge Weight To Concentration Ratio - WCR	5
Sludge Units - SLU	6
Settled Sludge Concentration - SSC	9
SIMPLIFIED MIXING FORMULAS	12
CFP Examples	13
ATC Examples	15
RSC Examples	17
AERATION TANK CHARACTERISTICS	20
Aeration Tank Sludge Units - ASU	22
Return Sludge Units - RSU	23
Aeration Tank Detention Time - ADT	24
ORGANIC LOADING AND PURIFICATION PRESSURES	25
Aeration Tank Loading Factors	25
Relative Purification Pressures	25
FINAL CLARIFIER CHARACTERISTICS	28
Final Clarifier Sludge Units - CSU	28
Final Clarifier Detention Time - CDT	32
Clarifier Sludge Detention Time - CSDT	33
Clarifier Surface Overflow Rate - OFR	35
PROCESS CHARACTERISTICS	36
Sludge Aeration Hours Per Day - SAH	36
Sludge Age - AGE & AAG	36
Sludge Concentration Ratio - SCR	39
CLARIFIER SLUDGE FLOW DEMAND - CSFD	40
MIXING FORMULA DEVELOPMENT	42
Simplified Mixing Formulas	42
Expanded Mixing Formulas	45
CLARIFIER SLUDGE FLOW DEMAND FORMULA DEVELOPMENT	47

DATA SOURCES AND TEXT ORGANIZATION

Calculation procedures used by the Waste Treatment Branch of the National Field Investigations Center - Cincinnati (NFIC-C) during technical assistance projects are described in this Part III of the Operational Control Procedures for the Activated Sludge Process. The suggested types and frequency of observations and control tests have been described in Parts I and II.

Essential flow data, such as waste water flow into the aeration tanks (AFI), return sludge flow (RSF), excess sludge wasted from the process (XSF), etc., are determined from the plant flow meters at each test period. Sludge and process characteristics, such as mixed liquor and return sludge concentrations (ATC and RSC), settled sludge volume (SSV), depth of sludge blanket in the final clarifier (DOB), etc., are determined by the control tests that have been described in Part II CONTROL TESTS.

These readings and control test results comprise the "Observed:" data that are entered in the formulas to determine the "Wanted:" information. Formulas and calculation examples are provided in this Part. The procedures for using these calculated values to evaluate sludge quality and process status, and to determine control adjustment requirements are described in subsequent Parts.

All calculations are performed in step-by-step fashion even though, in some cases, the end result could have been determined by one longer equation containing all the variables. This step-by-step method is preferred because some of the intermediate results are informative in themselves and are frequently used directly in other equations to calculate other process relationships. All examples are expressed in both metric and English units and a table of equivalents is printed inside the front cover. Figure 1 identifies tank sizes, flow rates and sludge concentrations used in the calculation examples. A complete list of all symbols and their definitions is included in the APPENDIX to this series. For convenient referencing, each calculation example is preceded by definitions of the symbols used in the example.

Some sections also include brief discussions of certain implicit assumptions, approximations, and use of the computed relationships. It is hoped that such statements will help clarify and add realism, even though they may be repeated and expanded in subsequent Parts describing process

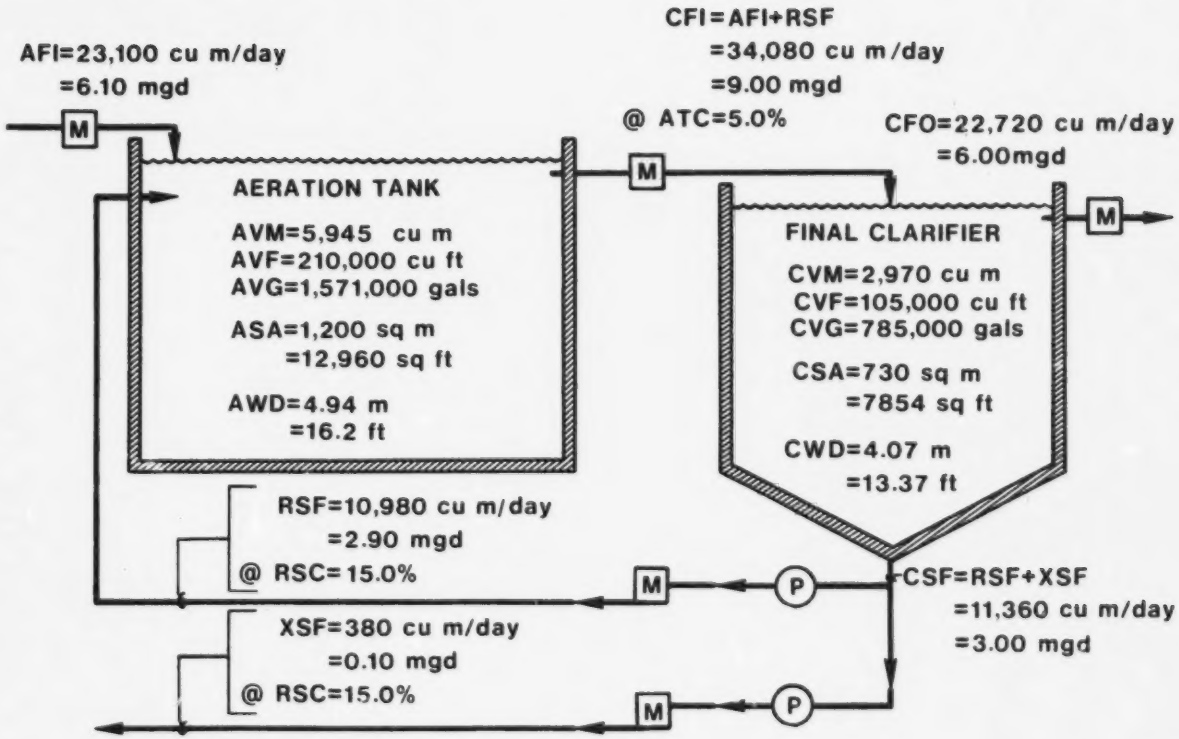


Figure 1

ACTIVATED SLUDGE SYSTEM
Volumes, Flows, and Sludge
Concentrations Used in the Examples

evaluation and control. Finally, the development of the mixing formulas and clarifier sludge flow demand formula are included in the last section of this Part for those who may be interested in their derivation.

Though the size of Part III may appear formidable, most calculations, except those in Part III B - Step Aeration and Contact Stabilization, are quite simple and straightforward.

Most of these routine process relationship calculations that are based on the sludge unit concept were proposed originally by E.B. Mallory. Some of the process loading factors and purification pressures presented reflect contemporary reaction kinetics principles.

The clarifier sludge flow demand formula (CSFD) and the associated sludge concentration ratio (SCR) and sludge weight-to-concentration ratio (WCR) that are used to calculate process control adjustment requirements were evolved by the author. He also developed the coordinated testing, calculation, evaluation and control procedures - "NFIC-C Procedures" - described in this pamphlet series.

ACTIVATED SLUDGE CHARACTERISTICS

ACTIVATED SLUDGE CONCENTRATIONS

ATC & RSC

Sludge concentration values used for calculating process relationships and control requirements are determined by the centrifuge test that is described in Part II, CONTROL TESTS.

Mixed liquor (ATC) and return sludge (RSC) concentrations are the most frequently used centrifuge values. These symbols are defined as follows:

ATC = Aeration Tank Concentration

The mixed liquor concentration determined by the standard 15-minute centrifuge test, expressed as the percent of the centrifuge tube occupied by the compacted mixed liquor sludge.

ATC=5%

RSC = Return Sludge Concentration

The return sludge concentration determined by the standard 15-minute centrifuge test, expressed as the percent of the centrifuge tube occupied by the compacted return sludge.

RSC=15%

SLUDGE WEIGHT-TO-CONCENTRATION RATIO - WCR

$$WCR = MLTSS/ATC$$

Mixed liquor concentration, expressed in percent and identified as ATC, should be determined by the standard centrifuge test during every control test period. At least once every 24 hours the weight of mixed liquor total suspended solids, expressed in mg/l and identified as MLTSS, should be determined by the laboratory balance from a portion of one of the samples that had been used to measure ATC.

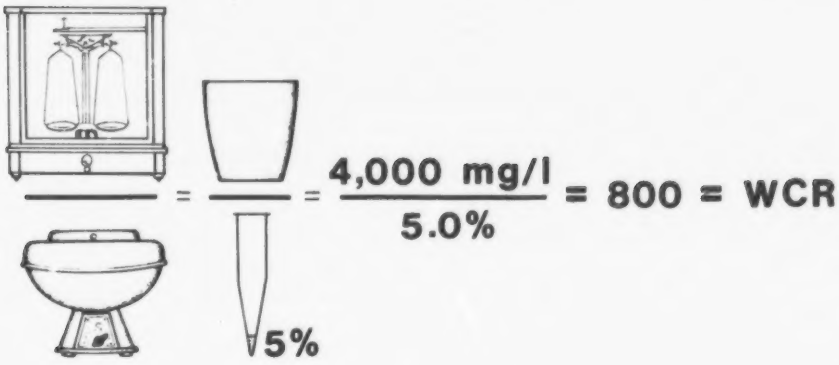
Though the solids concentration by centrifuge is used for most process control calculations discussed in these pamphlets, the ratio of solids by weight to solids by centrifuge (WCR) is one of the factors used to evaluate sludge oxidation and relative age.

SYMBOLS

ATC = Aeration Tank Concentration (%)
MLTSS = Mixed Liquor Total Suspended Solids, in mg/l, by laboratory balance.
WCR = Sludge Weight-to-Concentration Ratio

EXAMPLES

	"Young" Sludge	"Normal" Sludge	"Old" Sludge
Observed:			
MLTSS =	4,000 mg/l	4,000 mg/l	4,000 mg/l
ATC =	8.0%	5.0%	4.0%
Wanted: WCR			
Therefore:			
WCR =	MLTSS/ATC	MLTSS/ATC	MLTSS/ATC
=	4,000/8	4,000/5	4,000/4
=	500	800	1,000



The WCR of a properly oxidized sludge will usually approximate 800. The WCR for a young sludge will usually be less than 600, and that for an old, or over-oxidized, sludge may exceed 1,000.

The above examples also demonstrate that there is no one common constant to convert ATC to MLTSS for all types of sludges.

SLUDGE UNITS - SLU

SLU = Volume X Centrifuged Concentration/100

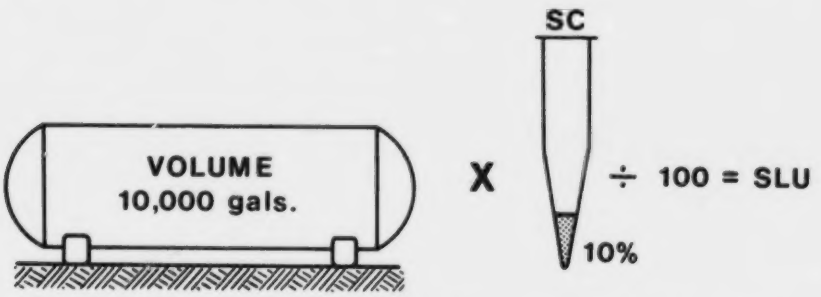
The number of sludge units in any tank, or portion of any tank or container, is determined by multiplying the volume occupied by the sludge (measured in cubic meters or gallons) times the sludge concentration (measured by the centrifuge test), but divided by 100 to convert the observed percent concentration to a decimal fraction).

SYMBOLS

SC = Sludge Concentration (% by centrifuge)
*SLU = Sludge Units

* Subscripts are not needed to distinguish between Metric or English sludge units because the type of SLU will obviously conform to the system (Metric or English) used by the operator.

Formulas to convert sludge units to pounds or kilograms and to convert Metric sludge units to English sludge units are included in the Equivalents Table inside the front cover.



10,000 gals. X 10.0 ÷ 100 = 1,000 SLU

EXAMPLES

Metric Units	English Units
Observed:	Observed:
Volume = 5,945 cu m SC = 5.0%	Volume = 1,571,000 gals SC = 5.0%
Wanted: SLU	
Therefore:	Therefore:
SLU = cu m x SC/100 = 5,945x5.0/100 = 297 SLU	SLU = gals x SC/100 = 1,571,000x5.0/100 = 78,550 SLU

DISCUSSION

The sludge unit, which is based on the centrifuge test, rather than the mass unit (expressed by weight - in kilograms or pounds) which is determined by the laboratory balance, is used for most process relationship calculations. This is because many properties that govern the sludge's purification capability also influence its compressibility and the end point concentration in the centrifuge tube. Additionally, the centrifuge test, which is also used to calculate WCR, is more rapid, and can be performed conveniently and more frequently than the suspended solids test.

The advantage of using sludge units rather than sludge weight can be illustrated by visualizing the different treatment capability of equal weights of different types of mixed liquor sludges.

Assume that two identical 10,000 cu m aeration tanks each contained an equal weight, but a different type or quality of mixed liquor sludge solids. Then further assume that Tank #1 contained a properly oxidized, highly active, flocculant sludge with a large percentage of voids and surface area. Let's also assume that the measured sludge concentration, by weight, was 2,400 mg/l. An adsorptive sludge of this type would have a WCR of about 800 and the ATC by centrifuge would have approximated 3.0%.

Then for Tank #1:

SLUDGE WEIGHT = cu m x mg/l / 1,000

= 10,000x2,400/1,000 = 24,000 kg

SLUDGE UNITS = cu m x ATC/100

= 10,000x3.0/100 = 300 SLU

Now let's assume that Tank #2 contained an over-oxidized less active, older, slightly knotted, dense floc that settled more rapidly but had less adsorptive capacity. And assume that the sludge concentration, by weight, also equaled 2,400 mg/l. A sludge of this type would have a WCR of about 1,200 and the ATC by centrifuge would have approximated 2.0%.

Then for Tank #2:

SLUDGE WEIGHT = 10,000 x 2,400/1,000 = 24,000 kg

SLUDGE UNITS = 10,000 x 2.0/100 = 200 SLU

If evaluated on the basis of weight alone, it would have appeared that both tanks provided equal purification capabilities. (2,400 mg/l and 24,000 kgs in each tank). But from an evaluation of sludge units it is evident that the first tank (300 SLU) contained 50% more sludge units than the second tank (200 SLU). Although the highly active sludge in the first tank would probably not perform 50% more work than the equal weight of less active and poorer quality sludge in the second tank, it certainly could produce a significantly better quality final effluent.

No similar comparison is made with an exceptionally young, fluffy, slowly settling bulking sludge since, in actual practice, such a sludge could not be held in the system. The WCR might be 300 and the centrifuged ATC of a 2,400 mg/l mixed liquor would equal 8.0%. Such a slowly settling sludge, though capable of producing a sparkling settlometer supernatant, would be washed out of the final clarifier long before ATC could be increased to the 8.0% level.

In summary, the sludge unit data would have indicated the potential superiority of sludge in the first tank, while the mass data, based on weight alone, would have erroneously indicated that the treatment capability of both sludges was equal.

SETTLED SLUDGE CONCENTRATION - SSC

SSC = 1,000 x ATC/SSV

Settled sludge concentration (SSC) values are calculated from the centrifuged mixed liquor concentration (ATC) and the settled sludge volume (SSV) values that are observed during the 60 minute settlometer test. Sludge quality, as determined by both the shape of the SSC curve and the 60 minute SSC value is discussed in PART IV SLUDGE QUALITY.

A table of calculated SSC values and the SSV and SSC curves are illustrated in the following example and in Figure 2.

SYMBOLS

ATC = Aeration Tank Concentration (%)
SSC = Settled Sludge Concentration (%)
SST = Sludge Settling Time (minutes)
SSV = Settled Sludge Volume (cc/l in settlometer)

EXAMPLE

Observed:

ATC = 3.0%
SSV = Values shown in Table 1.

Wanted: SSC Trend during the 60-minute test

Therefore:

TABLE 1.

ELAPSED TIME	OBSERVED	SSC = 1000 ATC/SSV		CALCULATED
SST (min.)	SSV (cc/l)			SSC (%)
0	1000	3000/1000	=	3.00
5	630	3000/630	=	4.76
10	470	3000/470	=	6.38
15	390	3000/390	=	7.69
20	340	3000/340	=	8.82
25	300	3000/300	=	10.00
30	275	3000/275	=	10.91
40	235	3000/235	=	12.76
50	215	3000/215	=	13.95
60	200	3000/200	=	15.00

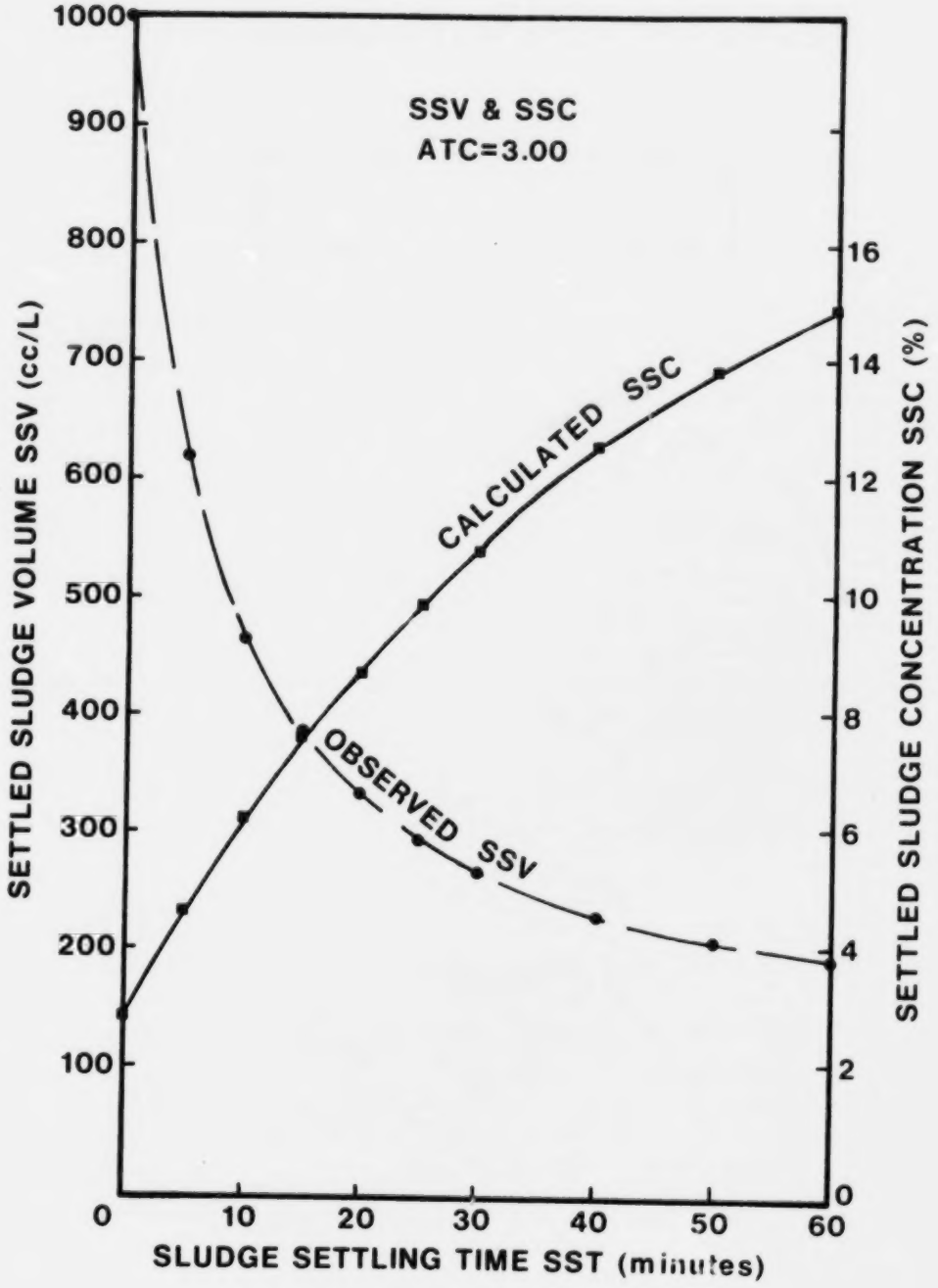


Figure 2

SLUDGE SETTLING AND
CONCENTRATION VS. TIME

SIMPLIFIED MIXING FORMULAS

$$CFP = ATC/(RSC-ATC)$$
$$ATC = (CFP \times RSC)/(CFP+1.0)$$
$$RSC = ATC+(ATC/CFP)$$

The mixing formulas based on the relationship between ATC, RSC, and CFP are used to calculate many process relationships and control adjustment demands needed to maintain optimum process equilibrium. They are also used to check waste water and return sludge flow meters, and can be used to determine either of these two flows if one of the two meters is missing or inoperative. At equilibrium, the clarifier sludge flow percentage (CFP) calculated from the mixed liquor and return sludge concentrations, and expressed decimally, will equal the CFP value determined by dividing the metered clarifier sludge removal flow rate (CSF) by the metered clarifier flow rate (CFO).

The mixing formulas have been simplified by neglecting final effluent suspended solids since that concentration is usually very small compared to the mixed liquor and return sludge concentrations. Development of the mixing formulas and expansions to include either primary effluent or final effluent suspended solids are included in the Derivation Section.

SYMBOLS

AFI = Aeration Tank Waste Water Flow-In (Usually primary effluent flow)
ATC = Aeration Tank Concentration (%)
CFI = Final Clarifier Flow-In (Mixed liquor Flow into Final Clarifier)
CFO = Final Clarifier Flow-Out (Final Effluent)
CFP = Final Clarifier Sludge Flow Percentage (Expressed decimally)
CSF = Final Clarifier Sludge Flow (Usually RSF+XSF)
RFP = Return Sludge Flow Percentage (As determined from flow meter readings)
RSC = Return Sludge Concentration (%)
RSF = Return Sludge Flow
XSF = Excess Sludge Flow to Waste

CFP EXAMPLES

CFP = ATC/(RSC-ATC)

To illustrate use of the CFP formula let's assume that the return sludge flow (RSF) meter failed and was taken out of service. In this case, the aeration tank flow-in (AFI) meter and the excess sludge flow to waste meter (XSF) were functioning and the operator could therefore calculate the return sludge flow and other needed process relationships from the ATC and RSC test data.

The measured flows and those flows calculated from the CFP formula are shown in Figure 3 and the calculation examples follow.

Metric Units	English Units
Observed:	**Observed:**
AFI = 23,100 cu m/day	AFI = 6.100 mgd
XSF = 380 cu m/day	XSF = 0.100 mgd
ATC = 5.0%	ATC = 5.0%
RSC = 15.0%	RSC = 15.0%
Wanted: CFP, CSF, RSF & RFP	
Therefore:	**Therefore:**
CFP = ATC/(RSC-ATC)	CFP = ATC/(RSC-ATC)
= 5.0/(15.0-5.0)	= 5.0/(15.0-5.0)
= 0.50	= 0.50
or 50%	or 50%
CFO = AFI-XSF	CFO = AFI-XSF
= 23,100-380	= 6.100 - 0.100
= 22,720 cu m/day	= 6.000 mgd
CSF = CFOxCFP	CSF = CFOxCFP
= 22,720x0.50	= 6.000x0.50
= 11,360 cu m/day	= 3.000 mgd
RSF = CSF-XSF	RSF = CSF-XSF
= 11,360-380	= 3.000-0.100
= 10,980 cu m/d	= 2.900 mgd

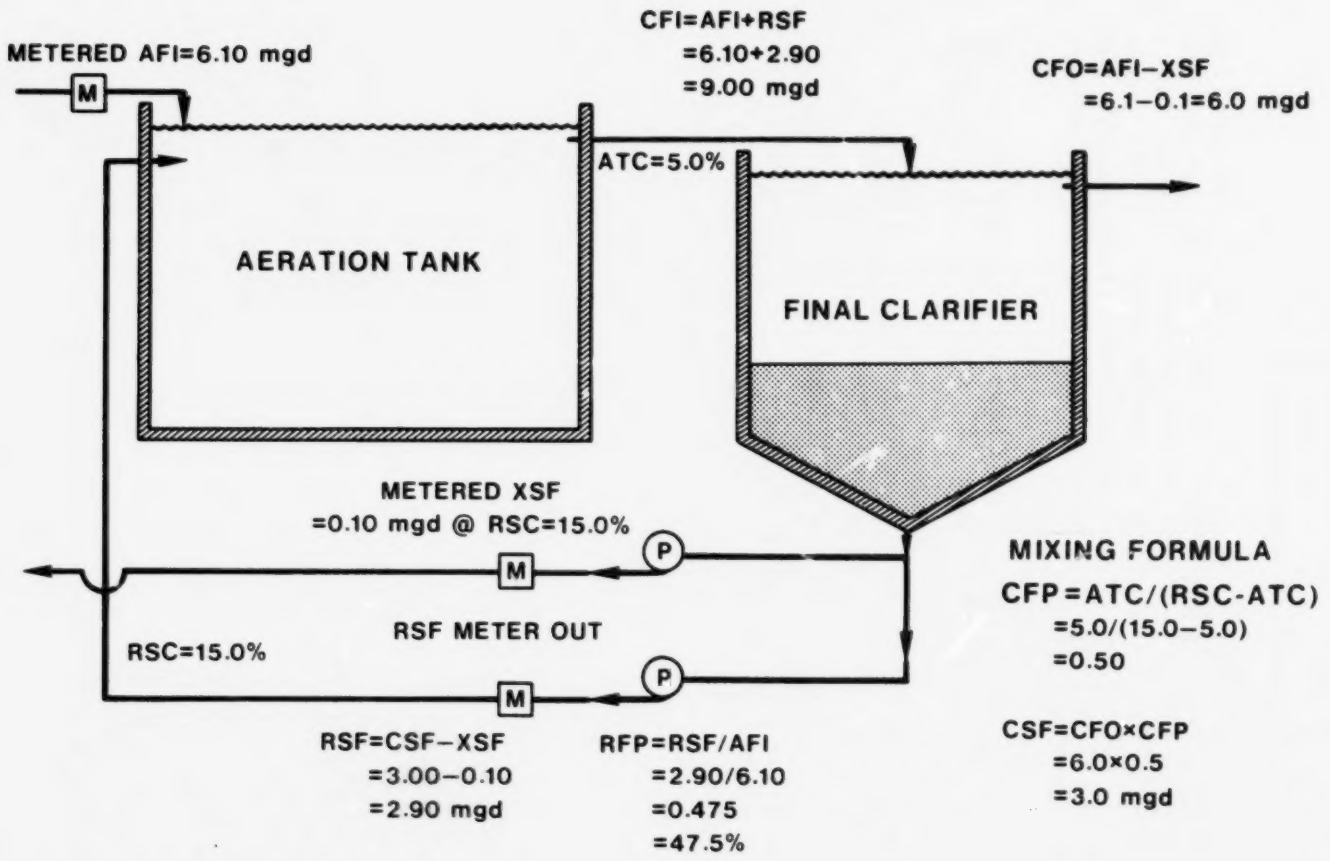


Figure 3

CFP MIXING FORMULA USED TO DETERMINE UNKNOWN FLOWS.

RFP = RSF/AFI	RFP = RSF/AFI
= 10,980/23,100	= 2.900/6.100
= 0.475	= 0.475
or 47.5%	or 47.5%

ATC EXAMPLES

ATC = (CFPxRSC)/(CFP+1.0)

In this case assume that the maximum capacity of the final clarifier sludge removal pump was 11,360 cu m/day (3.000 mgd) and the waste water flow into the aeration tanks (AFI) averaged 22,720 cu m/day (6.000 mgd) when sludge wasting was cut back to zero.

Furthermore, the mixed liquor could concentrate to an SSC of 15% after one hour in the Settlometer.

Then further assume that the operator wanted to know the maximum mixed liquor concentration (ATC) his process could maintain at equilibrium if he controlled his return sludge concentration (RSC) to equal the one hour SSC of 15%.

These conditions are illustrated in Figure 4 and the calculations follow.

Metric Units	English Units
Observed:	Observed:
AFI = 22,720 cu m/day	AFI = 6.000 mgd
CFO = AFI	CFO = AFI
CFO = 22,720 cu m/day	CFO = 6.000 mgd
XSF = 0.0	XSF = 0.0
CSF = 11,360 cu m/day	CSF = 3.000 mgd
RSC = 15%	RSC = 15%

Wanted: ATC at process equilibrium.

Therefore:	Therefore:
CFP = CSF/CFO	CFP = CSF/CFO
= 11,360/22,720	= 3.00/6.00
= 0.50	= 0.50

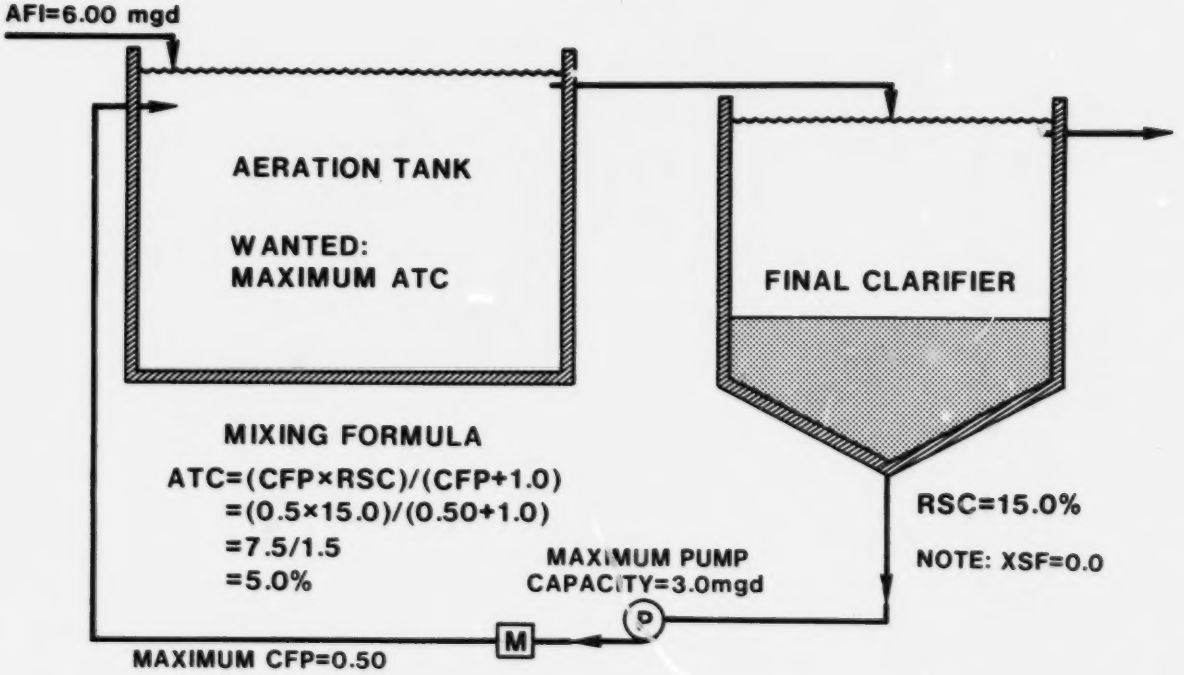


Figure 4

ATC MIXING FORMULA USED TO
DETERMINE MAXIMUM ATC

ATC = (CFPxRSC)/(CFP+1.0)	ATC = (CFPxRSC)/(CFP+1.0)
= (0.5x15)/(0.5+1.0)	= (0.5x15)/(0.5+1.0)
= 7.5/1.5	= 7.5/1.5
= 5.0%	= 5.0%

If sludge quality remained the same, the clarifier sludge pumping capacity would permit building ATC up to 5.0% while maintaining process equilibirum.

RSC EXAMPLES

RSC = ATC + (ATC/CFP)

In this case let's assume that the operator, who had been collecting clarifier sludge samples from near the surface of the pump station wet well, suspected that the solids content of these samples did not truly represent the solids content of the return sludge being pumped to the aeration tanks. He suspected solids-liquid separation in the deep wet well and therefore feared that the concentration of return sludge pumped from the bottom of the wet well might be greater than the measured 10.0% RSC of the sludge sample collected near the wet well surface.

He could check this out a number of ways, and one would be by use of the RSC mixing formula.

The plant conditions are illustrated in Figure 5 and the calculation examples follow:

Metric Units	English Units
Observed:	Observed:
CFI = 34,080 cu m/day	CFI = 9.000 mgd
CSF = 11,360 cu m/day	CSF = 3.000 mgd
XSF = 0.0	XSF = 0.0
ATC = 5.0%	ATC = 5.0%
Wanted: RSC	
Therefore:	
CFO = CFI-CSF	CFO = CFI-CSF
= 34,080-11,360	= 9.000-3.000
= 22,720 cu m/day	= 6.000 mgd

CFP = CSF/CFO
= 11,360/22,720
= 0.50

RSC = ATC + (ATC/CFP)
= 5.0 + (5.0/0.5)
= 15.0%

CFP = CSF/CFO
= 3.000/6.000
= 0.50

RSC = ATC + (ATC/CFP)
= 5.0 + (5.0/0.5)
= 15.0%

The operator would now know that the RSC should actually have approximated 15 instead of 10 percent. He would then relocate his return sludge sampling point to the sludge flow discharge channel or to some other location where a truly representative sample could be collected.

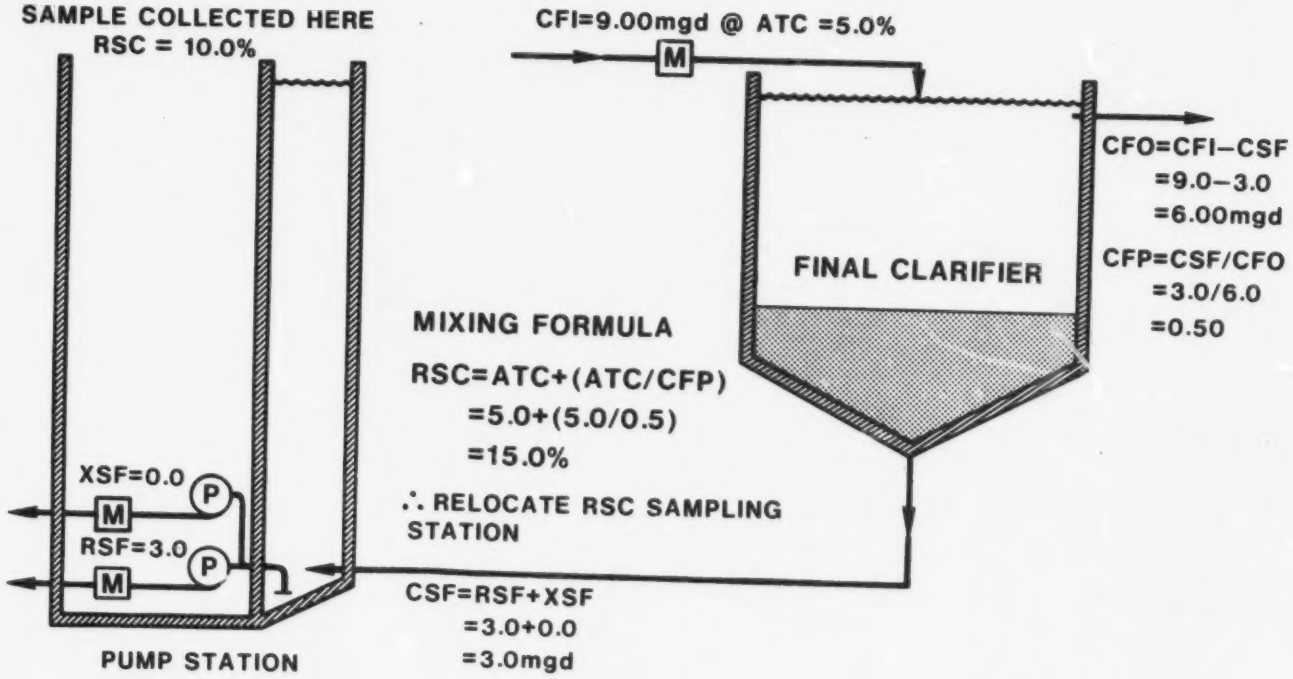


Figure 5

RSC MIXING FORMULA USED TO CHECK VALIDITY OF RSC TEST RESULTS

AERATION TANK CHARACTERISTICS

This section contains aeration tank sludge unit and detention time calculation examples. It also contains supplementary formulas and calculated aeration tank loading factors and purification pressures.

A coordinated evaluation of these with the final clarifier and process characteristics, that are defined in the next two Sections, reveal process status and purification potential.

This appears to be a good place to reemphasize that optimum plant performance and best final effluent quality are achieved by diligent, coordinated evaluation of all interrelated and interacting sludge and process characteristics. In all too many actual cases, activated sludge plants produce effluents below the quality level they are capable of achieving because process adjustments were aimed at meeting only a few independent, preconceived objectives.

Best treatment cannot be achieved by exclusive attempts to maintain either a constant mixed liquor sludge concentration or sludge age level, for example, while neglecting other coordinated process requirements needed to satisfy such demands as return sludge flow and clarifier sludge detention time.

Methods to determine the coordinated control adjustments needed to meet the various interrelated process requirements are discussed in Part V PROCESS CONTROL.

Aeration tank characteristics, flows and sludge concentrations used in the aeration tank calculations are illustrated in Figure 6.

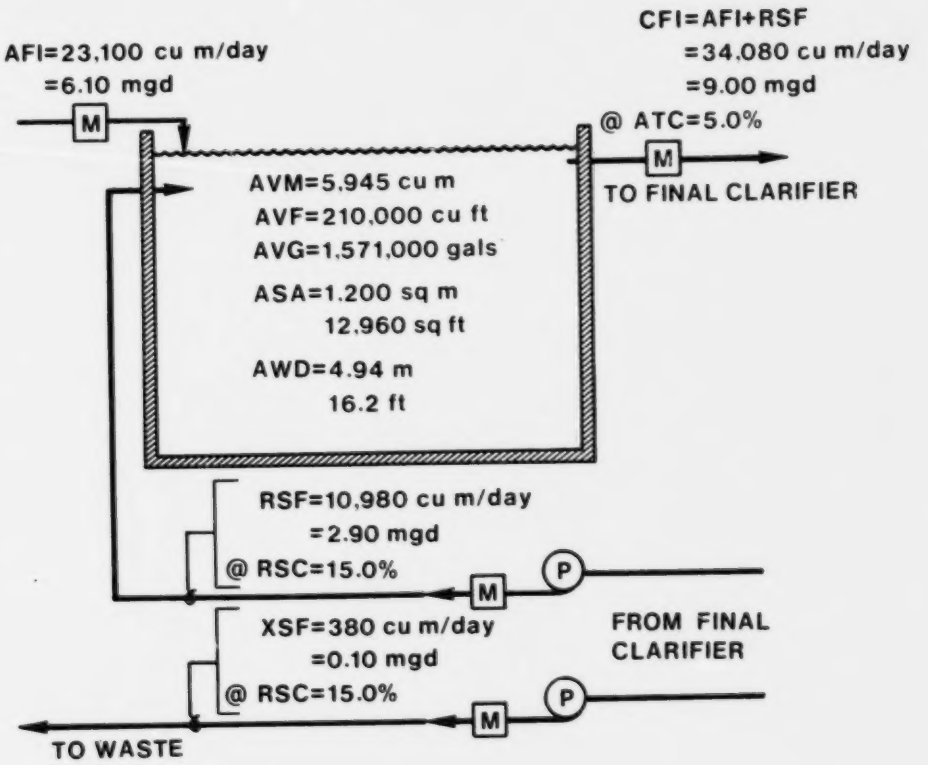


Figure 6

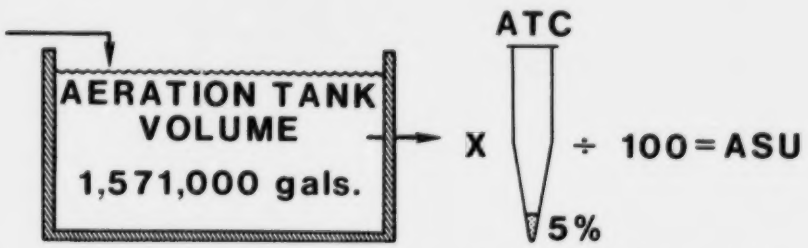
AERATION TANK
Volumes, Flows, and Sludge Concentrations Used in the Examples

AERATION TANK SLUDGE UNITS - ASU

ASU = AVxATC/100

SYMBOLS

ASU = Aeration Tank Sludge Units
ATC = Aeration Tank Concentration (%)
AV = Aeration Tank Volume
AVG = Aeration Tank Volume in gals
AVM = Aeration Tank Volume in cu m



1,571,000 gals. X 5.0÷100=78,550 SLU

EXAMPLES

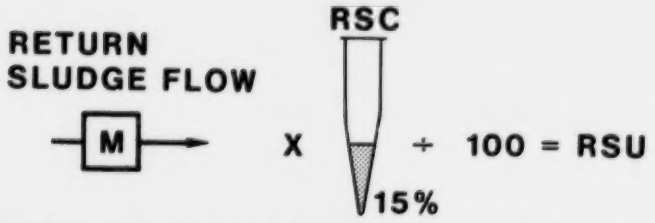
Metric Units	English Units
Observed:	Observed:
AVM = 5,945 cu m ATC = 5.0%	AVG = 1,571,000 gals ATC = 5.0%
Wanted: ASU	
Therefore:	Therefore:
ASU = AVMxATC/100 = 5,945x5.0/100 = 297	ASU = AVGxATC/100 = 1,571,000x5.0/100 = 78,550

RETURN SLUDGE UNITS - RSU

RSU = RSF x RSC/100

SYMBOLS

RSC = Return Sludge Concentration (%)
RSF = Return Sludge Flow
RSU = Return Sludge Units (to aeration tanks)



2,900,000 gals/day X 15.0÷100=435,000 RSU/day

EXAMPLES

Metric Units

Observed:

RSF = 10,980 cu m/day
RSC = 15.0%

Wanted: RSU

Therefore:

RSU = RSFxRSC/100
= 10,980x15/100
= 1650/day

English Units

Observed:

RSF = 2.900 mgd
RSC = 15.0%

Therefore:

RSU = RSFxRSC/100
= 2,900,000x15.0/100
= 435,000/day

AERATION TANK DETENTION TIME IN HRS - ADT

ADT@AFI = (AVx24)/AFI
ADT@TFL = (AVx24)/(AFI+RSF)

SYMBOLS

ADT = Aeration Tank Detention Time (hrs)
AFI = Aeration Tank Waste Water Flow-In (usually primary effluent flow)
AV = Aeration Tank Volume
AVG = Aeration Tank Volume in gals
AVM = Aeration Tank Volume in cu m
RSF = Return Sludge Flow
TFL = Total Flow to Aeration Tank (AFI+RSF)

EXAMPLES

Metric Units

Observed:

AVM = 5,945 cu m
AFI = 23,100 cu m/day
RSF = 10,980 cu m/day

Wanted: ADT@AFI & ADT@TFL

Therefore:

ADT@AFI = (AVMx24)/AFI
= (5,945x24)/23,100
= 6.18 hrs

ADT@TFL = (AVMx24)/(AFI+RSF)
= (5,945x24)/(23,100 +10,980)
= 4.19 hrs

English Units

Observed:

AVG = 1.571 million gal
AFI = 6.100 mgd
RSF = 2.900 mgd

Therefore:

ADT@AFI = (AVGx24)/AFI
= (1.571x24)/6.1
= 6.18 hrs

ADT@TFL = (AVGx24)/(AFI+RSF)
= (1.571x24)/(6.1+2.9)
= 4.19 hrs

ORGANIC LOADING AND PURIFICATION PRESSURES

AERATION TANK LOADING FACTORS

The following monitoring type BOD loading factors, that are calculated after the BOD test results are obtained, can be used to evaluate certain historical cause-and-effect relationships even though they cannot be used for day-to-day process control. Such factors, when related to actual plant performance, can be used to develop design criteria for future plant modifications and additions. (All symbols have been explained in previous sections.)

Metric Units	English Units
kg BOD/1000 AVM	lbs BOD/1000 AVF
kg BOD/ASU	lbs BOD/1000 ASU
kg BOD/kg MLVSS	lbs BOD/lb MLVSS

Similar calculations may be based on COD, TOC or other loading measurements.

RELATIVE PURIFICATION PRESSURES

When correlated with sludge quality, the following factors indicate process purification pressures. The first three factors can be determined rapidly after each control test. The last two factors, though more definitive, can only be calculated after the BOD test data are available.

This section only introduces additional factors, which when combined with other sludge quality indicators, can help the operator interpret process responses to control adjustments.

Metric Units	English Units
ATCxADT@AFI	ATCxADT@AFI
ATCxADT@TFL	ATCxADT@TFL
RSU/1000 cu m AFI	RSU/1000 gals AFI
ATCxADT@TFL/mg/l BODd	ATCxADT@TFL/mg/l BODd
RSU/kg of BODi	RSU/lb of BODi

All symbols except the following have been defined in previous sections.

BODi = Five-day biochemical oxygen demand of the waste water entering (in) the aeration tanks.

BODo = Five-day biochemical oxygen demand of the final clarifier effluent. (out)

BODd = Calculated net five-day biochemical oxygen demand of waste water and the "liquid portion" of the return sludge at the aeration tank entrance. (diluted waste water)

= (BODi+(BODoxRFP))/(1.0+RFP)

Except for the following BODd calculation, examples are not shown since all other intermediate calculations are those conventionally used by plant operators and the loading factors and purification pressure values are simple fractions of previously defined characteristics. Aeration tank detention times (ADT) are based on waste water flow alone (@AFI), or waste water flow plus return sludge flow (@TFL).

BODd EXAMPLE

BODd = (BODi+(BODoxRFP))/(1.0+RFP)
= (160+(10x0.475))/(1.0+0.475)
= 112 mg/l

Note: Return sludge usually contains less than 2.0% solids and the BOD 5 of the liquid portion (98%+ of the total return sludge flow) should therefore approximate the BOD 5 of the clarifier effluent. The entire return sludge flow, rather than the variable liquid fraction, is used to calculate BODd. This facilitates using normally available data directly rather than introducing additional required analyses and calculations. The logic is in line with some contemporary kinetics principles.

The following Metric and English unit results are included to permit checking the formulas and the examples given in previous pages.

Test Results	Metric Units	English Units
AFI	23,100 cu m/d	6.1 mgd
RSF	10,980 cu m/d	2.9 mgd
BCDi	160 mg/l	160 mg/l
BODo	10 mg/l	10 mg/l
MLVSS	3000 mg/l	3000 mg/l
RSTSS	12,000 mg/l	12,000 mg/l
ATC	5.0%	5.0%
RSC	15.0%	15.0%
AV	5945 cu m	0.210 million cu ft
AV	5945 cu m	1.571 million gals
Results of Intermediate Calculations		
BODd	112 mg/l	112 mg/l
BODi	3,700 kg/day	8,140 lbs/day
ASU	297 SLU	78,550 SLU
MLVSS	17,835 kg	39,300 lbs
RSTSS	131,700 kg/day	290,400 lbs/day
ADT@AFI	6.18 hrs	6.18 hrs
ADT@TFL	4.19 hrs	4.19 hrs
RFP	0.475	0.475
RSU	1,650/day	435,000/day
Aeration Tank Loadings		
BODi/AV	622 kg/1000 AVM	38.76 lbs/1000 AVF
BODi/ASU	12.4 kg/ASU	104 lbs/1000 ASU
BODi/MLVSS	0.207 g/g	0.207 lbs/lb
Purification Pressures		
ATCxADT@AFI	30.90	30.90
ATCxADT@TFL	20.95	20.95
ATCxADT@TFL/mg/l BODd	0.187	0.187
RSU/AFI	71.3 RSU/1000 cu m	71.3 RSU/1000 gals
RSU/BODi	0.446 RSU/kg BODi	53.4 RSU/lb BODi
RSTSS/BODi	35.66 kg/kg	35.66 lb/lb

FINAL CLARIFIER CHARACTERISTICS

This section includes calculation procedures for the following final clarifier characteristics that define process equilibrium, permit clarifier and process performance evaluation and dictate control adjustment requirements.

Final Clarifier Sludge Units - CSU
Final Clarifier Detention Time - CDT
Clarifier Sludge Detention Time - CSDT
Clarifier Surface Overflow Rate - OFR

The clarifier sludge detention time (CSDT) should be calculated after every control test for use along with the CSFD (clarifier sludge flow demand - described later) to determine the required clarifier sludge flow control adjustment. The number of sludge units in the final clarifier (CSU) is usually calculated from the 24-hour average of test records to determine the aerator to clarifier solids distribution ratio (SDR = ASU/CSU) and for use in sludge age calculations. The other values, CDT and OFR are used to document hydraulic and sludge loadings.

Final clarifier characteristics, flows and sludge concentrations used are illustrated in Figure 7.

FINAL CLARIFIER SLUDGE UNITS - CSU

$$CSU = BLV \times CSC/100$$

The sludge blanket volume (BLV) is readily calculated from the depth of blanket (DOB) readings described in Part II, CONTROL TESTS. For calculating the mean concentration of the clarifier sludge (CSC), it is implicitly assumed that sludge concentration will increase uniformly from a value approximating ATC at the upper surface of the accumulated sludge blanket to RSC at the bottom of the blanket. The mean clarifier sludge concentration (CSC) will then approximate the average of ATC and RSC.

The clarifier characteristics for the following CSU calculation examples are shown in Figure 8.

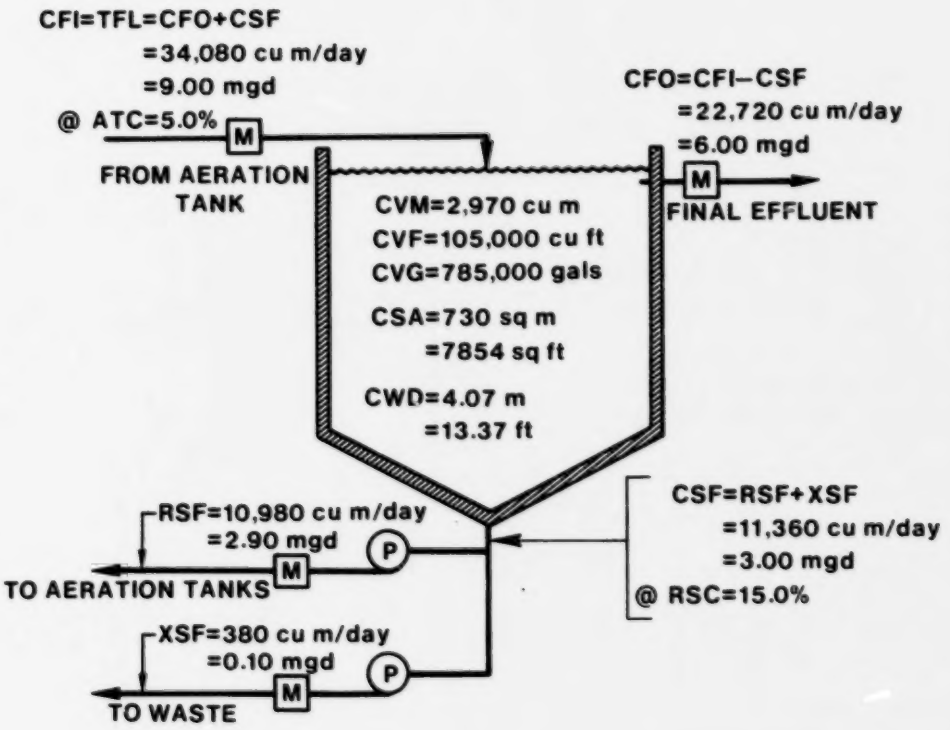


Figure 7

FINAL CLARIFIER
Volumes, Flows, and Concentrations
Used in the Examples

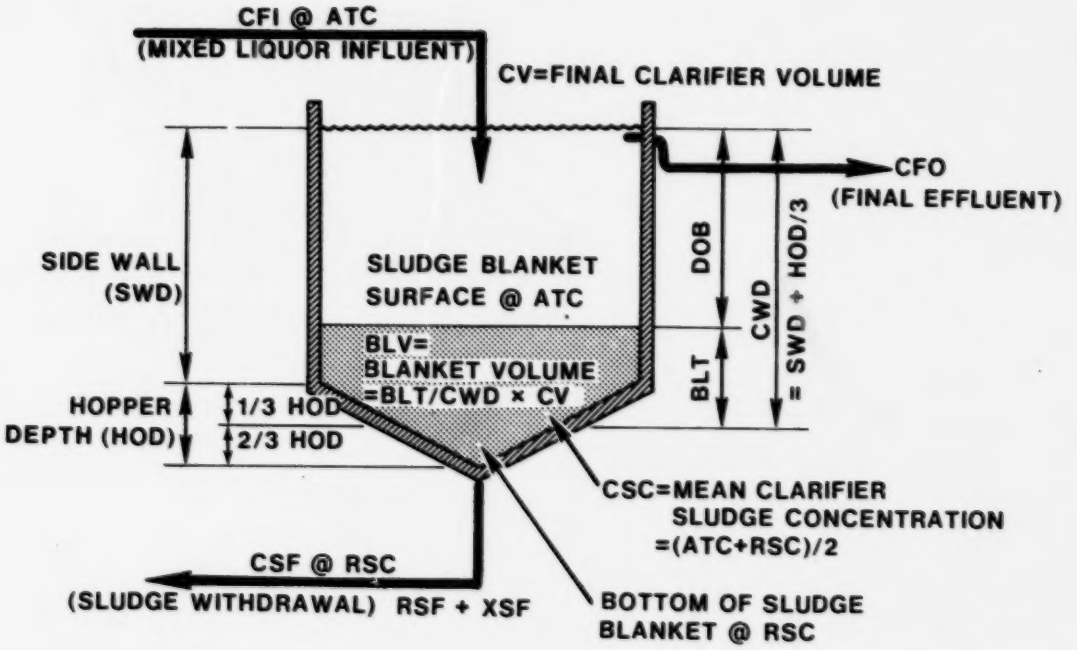


Figure 8

CSU = FINAL CLARIFIER SLUDGE UNITS

CSU = BLV×CSC/100

SYMBOLS

ATC = Aeration Tank Concentration (%)
BLT = Sludge Blanket Thickness (CWD - DOB)
BLV = Sludge Blanket Volume
CSA = Final Clarifier Surface Area
CSC = Mean Clarifier Sludge Blanket Concentration
= (ATC+RSC)/2
CSU = Final Clarifier Sludge Units
CV = Final Clarifier Volume
CVF = Final Clarifier Volume in Cubic Feet
CVG = Final Clarifier Volume in Gallons
CVM = Final Clarifier Volume in Cubic Meters
CWD = Final Clarifier Mean Water Depth
DOB = Depth of Sludge Blanket
(Measured from water surface to upper surface of the sludge blanket)
RSC = Return Sludge Concentration (%)
SWD = Clarifier Side Water Depth

EXAMPLES

Metric Units

Observed:

CVM = 2,970 cu m
CWD = 4.07 m
DOB = 2.71 m
ATC = 5.0%
RSC = 15.0%

Wanted: CSU

Therefore:

BLT = CWD-DOB
= 4.07 - 2.71
= 1.36 m

BLV = (BLT/CWD)xCVM
= (1.36/4.075)x2970
= 990 cu m

CSC = (ATC+RSC)/2
= (5.0+15.0)/2
= 10.0%

English Units

Observed:

CVG = 785,000 gals
CWD = 13.37 ft
DOB = 8.9 ft
ATC = 5.0%
RSC = 15.0%

Therefore:

BLT = CWD-DOB
= 13.37 - 8.9
= 4.47 ft

BLV = (BLT/CWD)xCVG
= (4.47/13.37)x785,000
= 262,400 gals

CSC = (ATC+RSC)/2
= (5.0+15.0)/2
= 10.0%

CSU = BLVxCSC/100
= 990x10.0/100
= 99 SLU

CSU = BLVxCSC/100
= 262,400x10.0/100
= 26,240 SLU

DISCUSSION

The mean sludge blanket concentration is calculated from the implicitly assumed upper surface (ATC) and bottom level (RSC) concentrations to eliminate the otherwise time consuming and impractical task of collecting and centrifuging many additional sludge samples at one- or two-foot depth intervals from each clarifier during each testing period.

These assumptions are quite realistic for full-load, optimum sludge quality and process balance. The actual upper and lower level concentrations may not, however, equal ATC and RSC when sludge settling and sewage flow rates diverge widely from optimum. Though the value calculated from each control test will not always be accurate, *the trend (increasing or decreasing) of the calculated sludge unit values will realistically represent the changes that are occurring.*

Since process evaluation and control policy are based on the study of established trends, rather than upon observation of single test results, this simplified calculation procedure is valid as well as convenient.

FINAL CLARIFIER DETENTION TIME - CDT

CDT = (CVx24)/CFI

SYMBOLS

CDT = Final Clarifier Detention Time based on CFI (hrs)
CFI = Final Clarifier Flow-In
CV = Final Clarifier Volume
CVG = Final Clarifier Volume in gals
CVM = Final Clarifier Volume in cu m

EXAMPLES

Metric Units	English Units
Observed:	Observed:
CVM = 2,970 cu m	CVG = 0.7850 million gal
CFI = 34,080 cu m/d	CFI = 9.000 MGD
Wanted: CDT	
Therefore:	Therefore:
CDT = (CVMx24)/CFI	CDT = (CVGx24)/CFI
= (2.970x24)/34,080	= (0.7850x24)/9.0
= 2.09 hrs	= 2.09 hrs

CLARIFIER SLUDGE DETENTION TIME - CSDT

CSDT = CSU/CSUO

The sludge detention time in the final clarifier is determined by dividing the number of sludge units accumulated in the clarifier by the rate at which sludge units are removed from the clarifier. See Figure 9.

SYMBOLS

CSDT = Final Clarifier Sludge Detention Time (hrs)
CSF = Final Clarifier Sludge Flow
CSU = Final Clarifier Sludge Units
CSUO = Final Clarifier Sludge Units-Out
RSC = Return Sludge Concentration (%)
RSF = Return Sludge Flow
XSF = Excess Sludge Flow to waste

EXAMPLES

Metric Units	English Units
Observed:	Observed:
CSU = 99	CSU = 26,240
RSC = 15.0%	RSC = 15.0%
RSF = 10,980 cu m/day	RSF = 2.900 mgd
XSF = 380 cu m/day	XSF = 0.100 mgd

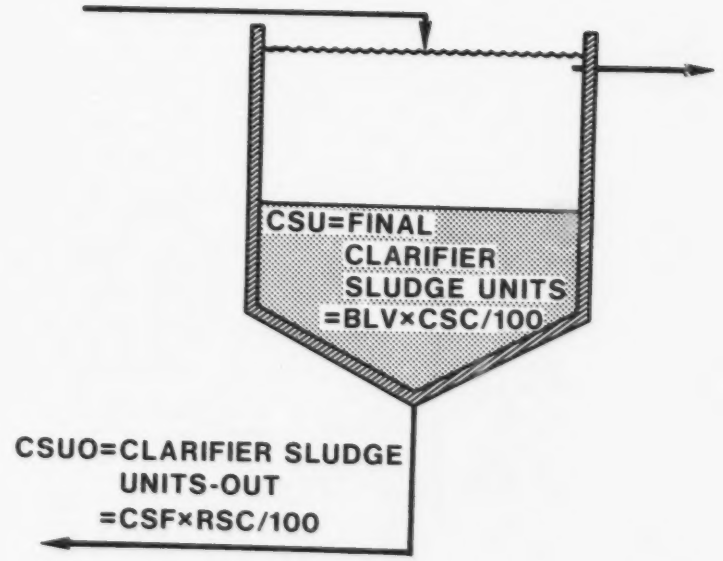


Figure 9

CSDT = CLARIFIER SLUDGE DETENTION TIME

CSDT = CSU/CSUO

Wanted: CSDT

Therefore:

CSF = RSF+XSF
= 10,980+380
= 11,360 cu m/day

CSUO = CSFxRSC/100
= (11,360x15.0)/100
= 1700 SLU/day
= 1700/24 = 71 SLU/hr

CSDT = CSU/CSUO
= 99/71 = 1.39 hrs

Therefore:

CSF = RSF+XSF
= 2.9+0.1
= 3.000 mgd

CSUO = CSFxRSC/100
= 3,000,000x15.0/100
= 450,000 SLU/day
= 450,000/24 = 18,750 SLU/hr

CSDT = CSU/CSUO
= 26,240/18,750 = 1.40 hrs

FINAL CLARIFIER SURFACE OVERFLOW RATE - OFR

OFR = CFO/CSA

SYMBOLS

CSA = Final Clarifier Surface Area
CFO = Final Clarifier Flow-Out (Final Effluent)
OFR = Final Clarifier Surface Overflow Rate

EXAMPLES

Metric Units

Observed:

CFO = 22,720 cu m/d
CSA = 730 sq m

Wanted: OFR

Therefore:

OFR = CFO/CSA
= 22,720/730
= 31.1 cu m/day/sq m

English Units

Observed:

CFO = 6.000 mgd
CSA = 7854 sq ft

Therefore:

OFR = CFO/CSA
= 6,000,000/7,854
= 764 gals/day/sq ft

PROCESS CHARACTERISTICS

SLUDGE AERATION HOURS - SAH

$$SAH = (ADT \times 24)/(ADT+CSDT)$$

Activated sludge oxidation is influenced by the number of hours the sludge resides in the aeration tanks during each 24-hour cycle.

SYMBOLS

ADT - Aeration Tank Detention Time
CSDT - Final Clarifier Sludge Detention Time
SAH - Sludge Aeration Hours per day

EXAMPLES

Observed:

ADT = 4.19 hrs (@TFL)
CSDT = 1.39 hrs

Wanted: SAH

Therefore:

SAH = (ADTx24)/(ADT+CSDT)
= (4.19x24)/(4.19+1.39)
= 18.0 hrs/day

SLUDGE AGE - AGE & AAG

$$AGE = (ASU+CSU) / TXU/day$$
$$AAG = AGE \times SAH/24$$

The following method of calculating sludge age is used while the Waste Treatment Branch is developing an improved method. The improved method will be included in a future

issue of this pamphlet series if it proves practical and more realistic.

Sludge age, being the average time that sludge solids remain in the activated sludge plant, can vary from few to many days. Using 24-hour average data for each day's sludge age calculation could obviously cause gross errors. If no sludge were wasted on one day, for example, the calculation would erroneously imply an infinite sludge age.

It is therefore suggested that the 7-day moving averages of TSU, TXU etc, be used to compute sludge age. Seven days is a reasonable time span and it includes all data for every day in a calendar week. For instance, the sludge age calculation on Thursday would be based on the averages of all appropriate data collected during the previous Friday, Saturday, Sunday, Monday, Tuesday, Wednesday and the current Thursday. This procedure also minimizes the discrepancy that can be introduced when no sludge is wasted for a day or two. In this case, the one or two zeros would be averaged in with the other TXU values for che remaining 5 or 6 days in the 7-day moving average time interval. The moving average concept is described and illustrated in the Appendix.

Obviously, with a clear final effluent ESU becomes very small. Under this condition TXU will nearly equal XSU. But, the ESU term becomes significant under "bulking" conditions, for example, as final effluent becomes degraded, i.e solids are discharged with the final clarifier overflow.

SYMBOLS

AAG - Aeration Age. Number of days the sludge was subjected to aeration.
AGE - Sludge Age in days.
ASU - Aeration Tank Sludge Units
CFO - Final Clarifier Flow-Out
CSU - Final Clarifier Sludge Units
ESU - Final Effluent Sludge Units
FEC - Final Effluent Concentration (%)
FETSS - Final Effluent Total Suspended Solids (mg/l)
SAH - Sludge Aeration Hours per day
TXU - Total Excess Sludge Units removed (XSU+ESU)
WCR - Sludge Weight-to-Concentration Ratio
XSC - Excess Sludge Concentration
XSF - Excess Sludge Flow to Waste
XSU - Excess Sludge Units Wasted

EXAMPLES

Metric Units

Observed:

ASU = 297 SLU
CSU = 99 SLU
XSF = 380 cu m/day
XSC = 15.0%
CFO = 22,720 cu m/day
FETSS = 10.0 mg/l
WCR = 800
SAH = 18 hrs/day

Wanted: AGE & AAG

Therefore:

XSU = XSFxXSC/100
= 380x15.0/100
= 57 SLU/day

FEC = FETSS/WCR
= 10/800
= 0.0125%

ESU = CFOxFEC/100
= 22,720x0.0125/100
= 2.84 SLU/day

TXU = XSU+ESU
= 57+3
= 60 SLU/day

AGE = (ASU+CSU)/TXU/day
= (297+99)/60
= 6.6 days

AAG = AGExSAH/24
= 6.6x18/24
= 5.0 days

English Units

Observed:

ASU = 78,550 SLU
CSU = 26,240 SLU
XSF = 0.100 mgd
XSC = 15.0%
CFO = 6.0 mgd
FETSS = 10.0 mg/l
WCR = 800
SAH = 18 hrs/day

Therefore:

XSU = XSFxXSC/100
= 100,000x15.0/100
= 15,000 SLU/day

FEC = FETSS/WCR
= 10/800
= 0.0125%

ESU = CFOxFEC/100
= 6,000,000x0.0125/100
= 750 SLU/day

TXU = XSU+ESU
= 15,000+750
= 15,750 SLU/day

AGE = (ASU+CSU)/TXU/day
= (78,550+26,240)/15,750
= 6.6 days

AAG = AGExSAH/24
= 6.6x18/24
= 5.0 days

SLUDGE CONCENTRATION RATIO - SCR

$$SCR = SSC60/RSC$$

The sludge concentration ratio reveals process balance status, and indicates control adjustment needs. It shows how closely the controlled return sludge concentration approached the desired settled sludge concentration that had been determined from the settlometer test.

The SSC settlometer test results should be plotted on a trend chart as illustrated in the Appendix. The RSC values should also be shown, as enlarged dots, on this trend chart to indicate how far they may have strayed from the desired SSC values.

The SCR, therefore, refines impressions received from the trend chart and provides numerical values that can be used to analyse process balance and to set target values for return sludge flow demand calculations.

An SCR between 1.0 and 1.2 usually indicates good balance. Values less than 0.9 or greater than 2.0 reveal the need for process adjustment.

SYMBOLS

RSC = Return Sludge Concentration (%)
SCR = Sludge Concentration Ratio
SSC60 = Settled Sludge Concentration at 60 minutes

EXAMPLES

Observed:	Case A	Case B	Case C
SSC60 =	15.0	8.0	16.5
RSC =	14.0	10.0	7.5

Wanted: SCR

Therefore:

SCR =	SSC60/RSC	SSC60/RSC	SSC60/RSC
=	15.0/14.0	8.0/10.0	16.5/7.5
=	1.07	0.80	2.2

The SCR in Case A reveals good process balance, but the SCR in Case B is too low and that in Case C is too high.

CLARIFIER SLUDGE FLOW DEMAND - CSFD

$$CSFD = CSF \times (RSC-ATC)/(SSC-ATC)$$

This CSFD Formula is used to determine the clarifier sludge removal flow rate (CSF) needed to maintain proper process balance. It should be computed at the end of each testing period, after which the operator should adjust the CSF to equal the CSFD.

The operator should also compute the CSDT, as shown in the final clarifier section, to determine whether the final clarifier sludge residence time approximates 1.0 hour, or is at least within the tolerable limits of from 0.75 to 1.5 hours.

The use of these formulas for process evaluation and control is discussed in Part IV PROCESS CONTROL.

SYMBOLS

ATC = Aeration Tank Concentration (%)
CSF = Final Clarifier Sludge Flow
CSFD = Clarifier Sludge Flow Demand
RSC = Return Sludge Concentration (%)
SSC = Settled Sludge Concentration (%)

EXAMPLES

Metric Units

Observed:

CFO = 22,720 cu m/day
CSF = 11,360 cu m/day
ATC = 5.0%
RSC = 15.0%
SSC = 13.0%

English Units

Observed:

CFO = 6.000 mgd
CSF = 3.000 mgd
ATC = 5.0%
RSC = 15.0%
SSC = 13.0%

Wanted: CSFD needed to reduce RSC from 15.0 to 13.0

Therefore:

CSFD = CSFx(RSC-ATC)
/(SSC-ATC)

= 11,360 (15.0-5.0)
/(13.0-5.0)

= 11,360x10.0/8.0

= 14,200 cu m/day

Therefore:

CSFD = CSFx(RSC-ATC)
/(SSC-ATC)

= 3.0(15.0-5.0)
/(13.0-5.0)

= 3.0x10.0/8.0

= 3.75 mgd

MIXING FORMULA DEVELOPMENT

SYMBOLS FOR MIXING FORMULAS

AFI = Aeration Tank Waste Water Flow-In
ATC = Aeration Tank Concentration (%)
CFI = Final Clarifier Flow-In
CFO = Final Clarifier Flow-Out (Final Effluent)
CFP = Final Clarifier Sludge Flow Percentage (expressed decimally)
CSF = Clarifier Sludge Flow (Usually = RSF+XSF)
FEC = Final Effluent Solids Conc. (%)
FETSS = Final Effluent Total Suspended Solids (mg/l)
MLTSS = Mixed Liquor Total Suspended Solids (mg/l)
PEC = Primary Effluent Solids Conc. (%)
PETSS = Primary Effluent Total Suspended Solids (mg/l)
RSC = Return Sludge Concentration (%)
RSF = Return Sludge Flow
RSP = Return Sludge Flow Percentage based on a mass balance around the inlet end of the aeration tank (expressed decimally)
SLU = Sludge Units
CSUI = Final Clarifier Sludge Units-In
CSUO = Final Clarifier Sludge Units-Out
WCR = Sludge Weight-to-Concentration Ratio
XSF = Excess Sludge Flow to Waste

SIMPLIFIED MIXING FORMULAS

(See Figure 10)

A. Define the Flow Equality.

The sum of the final effluent and clarifier sludge flow out of the final clarifier must equal the mixed liquor flow into the clarifier.

Flow Out = Flow In

$$CFO + CSF = CFI \qquad (1)$$

Express CSF and CFI as functions of CFO and CFP.

$$CSF = CFO \times CFP \qquad (2)$$

$$CFI = CFO\ (1.0+CFP) \qquad (3)$$

Now substitute the right hand terms of equations (2) and (3) for CSF and CFI in equation (1)

$$\text{Flow Out} = \text{Flow In}$$
$$CFO + (CFO \times CFP) = CFO(1.0 + CFP) \qquad (4)$$

B. Define the Sludge Unit Equality

The number of sludge units flowing out of the final clarifier will be the sum of FEC/100 multiplied by the final effluent flow plus RSC/100 multiplied by the clarifier sludge flow. The number of sludge units entering the clarifier will be ATC/100 multiplied by the mixed liquor flow.

By multiplying the terms in equation (4) by the appropriate concentrations, the sludge unit equality becomes:

$$CFO \times FEC/100 + (CFO \times CFP) \times RSC/100 = CFO\ (1.0 + CFP) \times ATC/100 \qquad (5)$$

The final effluent suspended solids concentration is exceedingly low compared to the mixed liquor and return sludge concentrations in an activated sludge plant that is performing properly. Under such conditions, the number of sludge units carried out in the final effluent can be neglected and equation (5) can be simplified to:

$$CFO \times CFP \times RSC/100 = CFO\ (1.0 + CFP) \times ATC/100 \qquad (6)$$

After cancelling the common CFO and 100 terms from both sides of equation (6) it can be further simplified to include only ATC, RSC and CFP as follows:

$$CFP \times RSC = (1.0 + CFP) \times ATC$$
$$CFP \times RSC = ATC + (CFP \times ATC)$$
$$(CFP \times RSC) - (CFP \times ATC) = ATC$$
$$CFP\ (RSC - ATC) = ATC$$
$$CFP = ATC\ /\ (RSC - ATC) \qquad (7)$$

The CFP equation (7) can now be transformed to the other two mixing formulas so that any single unknown can be calculated from the other two known or measured values.

$$CFP = ATC/(RSC-ATC)$$
$$ATC = CFP \times RSC/(CFP+1.0)$$
$$RSC = ATC+(ATC/CFP)$$

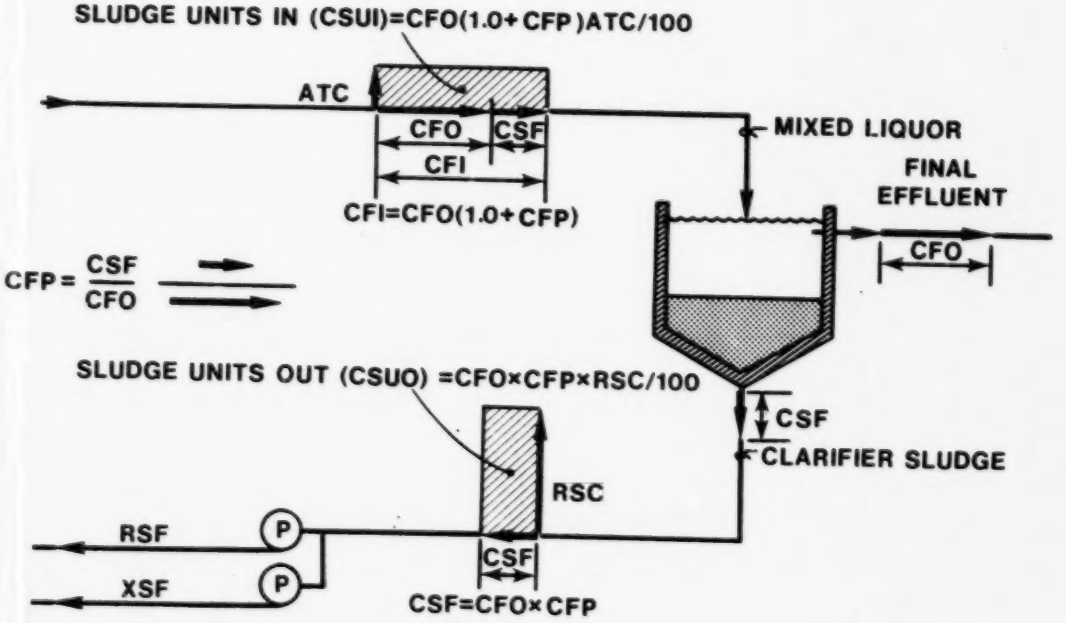


Figure 10

MASS BALANCE FOR
MIXING FORMULA DEVELOPMENT

$CSUI = CSUO$

$CFO(1.0+CFP)ATC = CFO \times CFP \times RSC$

EXPANDED MIXING FORMULAS

TO INCLUDE SIGNIFICANT PRIMARY EFFLUENT (PEC) OR FINAL EFFLUENT (FEC) SUSPENDED SOLIDS CONCENTRATIONS.

In high rate activated sludge plants for example, where the primary effluent suspended solids concentration may be significant compared to very low mixed liquor suspended solids concentrations, it is usually necessary to use mixing formulas that have been expanded to account for primary effluent solids.

Recognition and use of final effluent solids concentrations in expanded mixing formulas may also be necessary whenever significant amounts of sludge solids are washed out of the process final effluent during sludge "bulking".

In either case, a preliminary calculation is usually necessary to convert the primary effluent or final effluent suspended solids concentrations to equivalent centrifuge values (PEC and FEC) before using the expanded formulas. Since the sludge weight to centrifuged sludge concentration ratio (WCR) is usually determined daily, these approximate centrifuge concentration equivalents (PEC and FEC) can be computed as follows:

Primary Effluent	Final Effluent
PEC = PETSS/WCR	FEC = FETSS/WCR
Observed:	Observed:
PETSS = 240 mg/l WCR = 800	FETSS = 480 mg/l WCR = 800
Wanted: PEC	Wanted: FEC
Therefore:	Therefore:
PEC = PETSS/WCR = 240/800 = 0.30%	FEC = FETSS/WCR = 480/800 = 0.60%

The expanded formulas can then be derived according to the same mass balance techniques that were described for the Simplified Mixing Formula development.

CFO and FEC must, however, be included in the derivation to account for sludge units in the final effluent.

AFI and PEC must be included in the derivation of the formulas that are expanded to include primary effluent solids. Since these formulas are based on a mass balance of solids entering and leaving the aeration tanks, AFI, RSF and RSP are used instead of the CFO, CSF and CFP values that were used in the mass balance around the final clarifier.

Such derivations will then provide the following two sets of mixing formulas to include significant final effluent or primary effluent suspended solids concentrations:

FOR SIGNIFICANT FINAL EFFLUENT SOLIDS

```
CFP = (ATC-FEC)/(RSC-ATC)
ATC = (CFPxRSC)+FEC/(CFP+1.0)
RSC = ATC+ (ATC-FEC)/CFP
```

FOR SIGNIFICANT PRIMARY EFFLUENT SOLIDS

```
RSP = (ATC-PEC)/(RSC-ATC)
ATC = (RSPxRSC)+PEC/(RSP+1.0)
RSC = ATC+ (ATC-PEC)/RSP
```

CLARIFIER SLUDGE FLOW DEMAND FORMULA DEVELOPMENT

SYMBOLS FOR THE CLARIFIER SLUDGE FLOW DEMAND FORMULA

ATC = Aeration Tank Concentration (%)
CFO = Final Clarifier Flow-Out (Final Effluent)
CSF = Final Clarifier Sludge Flow
CFP = Final Clarifier Sludge Flow Percentage (expressed decimally)
CSUI = Final Clarifier Sludge Units-In (Mixed Liquor)
CSUO = Final Clarifier Sludge Units-Out (Return plus waste sludge)
CSFD = Clarifier Sludge Flow Demand
RSC = Return Sludge Concentration (%)
SSC = Settled Sludge Concentration (%)

DEVELOPMENT OF THE CLARIFIER SLUDGE FLOW DEMAND FORMULA

(SEE FIGURE 11)

The CSFD formula is developed by expressing the clarifier sludge flow as a percent of the sewage flow.

$$CSF = CFO \times CFP \qquad (1)$$

CFP is then expressed in terms of RSC and ATC according to the mixing formulas.

$$CFP = ATC/(RSC-ATC) \qquad (2)$$

The solids concentration relationship in equation (2) is now substituted for CFP in equation (1) and:

$$CSF = CFO \times ATC/(RSC-ATC) \qquad (3)$$

By transposing the terms in equation (3) it becomes:

$$CFO \times ATC = CSF \times (RSC-ATC) \qquad (4)$$

Substituting the desired clarifier sludge concentration (SSC) and the unknown clarifier sludge flow demand (CSFD),

for RSC and CSF respectively in equations (1), (2), and (3) will give:

$$CFOxATC = CSFD(SSC-ATC) \qquad (5)$$

Since the right hand terms in equations (4) and (5) are each equal to (CFOxATC), they are equal to each other, and:

$$CSFD(SSC-ATC) = CSF(RSC-ATC)$$

$$\boxed{CSFD = CSF(RSC-ATC)/(SSC-ATC)}$$

DISCUSSION AND CHECK ON THE FORMULA

The number of sludge units in the mixed liquor entering the final clarifier must equal, or approximate in actual practice, the number of sludge units in the clarifier sludge pumped out from the bottom of the clarifier.

Though the return sludge concentration (RSC) will change rapidly in response to a clarifier sludge flow (CSF) adjustment, the mixed liquor concentration (ATC) entering the clarifier will change only slightly, if at all, when the process balance is near optimum equilibrium.

Following is a mass balance check on the results from the CSFD example in the Process Characteristics Section.

CSUI must equal CSUO

Observed:

CSUI = (6.0+3.0)x5.0/100 = 0.450 million SLU/day
CSUO = 3.0x15.0/100 = 0.450 million SLU/day

The observed sludge units entering the final clarifier equal those leaving the clarifier.

Demand:

CSUI = (6.0+3.75)x5.0/100 = 0.4875 million SLU/day
CSUO = 3.75x13.0/100 = 0.4875 million SLU/day

Sludge units entering the final clarifier will equal those leaving the clarifier after the clarifier sludge is increased from 3.0 mgd to meet the 3.75 mgd clarifier sludge flow demand.

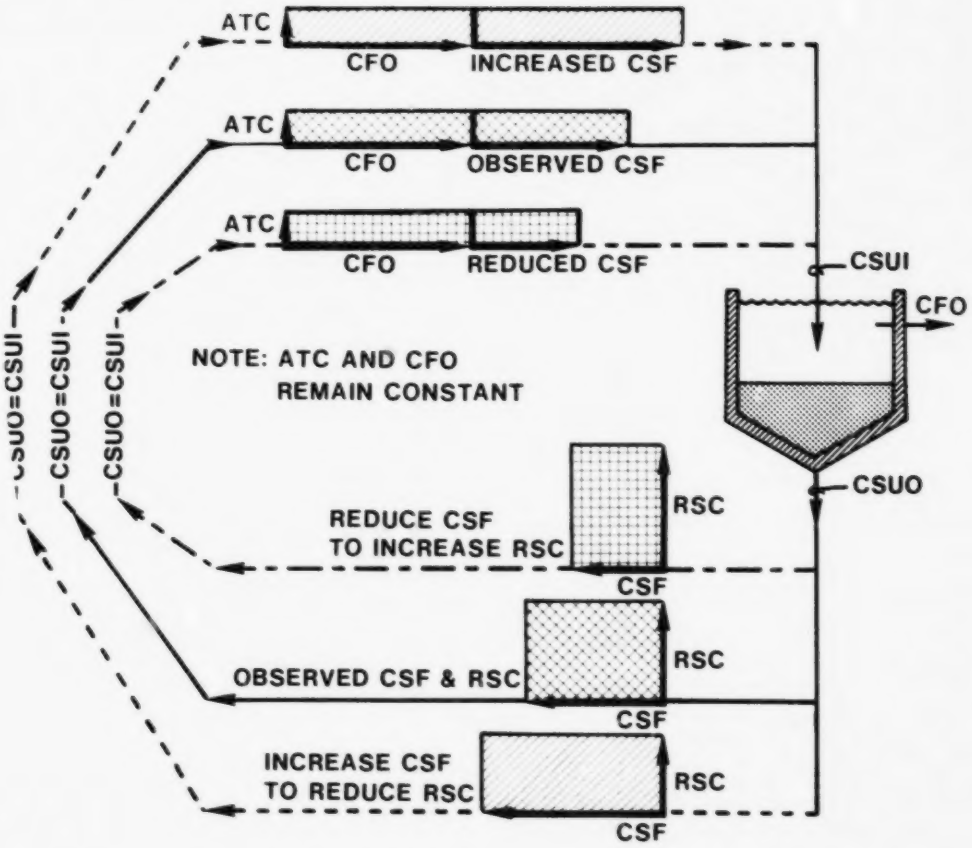


Figure 11

MASS BALANCE FOR CSFD

CFD = CSF(RSC−ATC)/(SSC−ATC)

☆ U.S. GOVERNMENT PRINTING OFFICE 1972 — 7-4-11/1091

SUMMARY OF

FORMULAS AND CALCULATED RESULTS

PARAMETERS	FORMULAS OR PROCEDURE	VALUES SHOWN IN EXAMPLE CALCULATIONS		EXAMPLE REFERENCE ON PAGE
		METRIC UNITS	ENGLISH UNITS	
HYDRAULIC LOADINGS				
ADT @ AFI	(AV x 24) / AFI	6.18 HRS	6.19 HRS	24
ADT @ TFL	(AV x 24) / (AFI + RSF)	4.19 HRS	4.19 HRS	24
CDT	(CV x 24) / CFI	2.09 HRS	2.09 HRS	33
OFR	CFO / CSA	31.1 CU M/DAY/SQ M	764 GPD/SQ FT	35
BOD LOADINGS				
BODi / AV	WT OF BODi / 1000 AV	622 KG/1000 AVM	38.76 LBS/1000 AVF	27
BODi / ASU	WT OF BODi / ASU	12.4 KG/ASU	104 LBS/1000 ASU	27
BODi / MLVSS	WT OF BODi / WT OF MLVSS	0.207 KG/KG	0.207 LBS/LB	27
PURIFICATION PRESSURES				
ATC x ADT @ AFI	DIRECT CALCULATION	30.90	30.90	27
ATC x ADT @ TFL	DIRECT CALCULATION	20.95	20.95	27
ATC x ADT / MG/L BODd	DIRECT CALCULATION	0.187	0.187	27
RSU / AFI	DIRECT CALCULATION	71.3 RSU/1000 CU M	71.3 RSU/1000 GAL	27
RSU / AFI BODi	DIRECT CALCULATION	0.446 RSU/KG BODi	53.4 RSU/LB BODi	27
RSTSS / BODi	WT OF RSTSS / WT OF BODi	35.66 KG/KG	35.66 LB/LB	27
SLUDGE QUALITY				
SSV 5	SETTLOMETER READING	630 CC/L	630 CC/L	10
SSV60	SETTLOMETER READING	200 CC/L	200 CC/L	10
* ATC	CENTRIFUGE READING	3 %	3 %	10
SSC60	1000 x ATC / SSV60	15 %	15 %	10
SCR	SSC60 / RSC	0.8 to 2.2	0.8 to 2.2	39
MCR	MLTSS / ATC	500 TO 1,000	500 TO 1,000	5
SIMPLE MIXING FORMULAS				
CFP	ATC / (RSC - ATC)	0.50	0.50	13
ATC	(CFP x RSC) / (CFP + 1.0)	5 %	5 %	17
RSC	ATC + (ATC / CFP)	15.0 %	15.0 %	18
PROCESS RELATIONSHIPS				
DOB	MEASURED	2.71 M	8.9 FT	31
BLT	CWD - DOB	1.36 M	4.47 FT	31
BLV	(BLT / CWD) x CV	990 CU M	262,400 GALS	31
CSC	(ATC + RSC) / 2	10 %	10 %	31
ASU	AV x ATC / 100	297 SLU	78,550 SLU	22
CSU	BLV x CSC / 100	99 SLU	26,240 SLU	32
TSU	ASU + CSU	396 SLU	104,790 SLU	-
RSU	RSF x RSC / 100	1,650 SLU/DAY	435,000 SLU/DAY	23
SDR	ASU / CSU	3.0	3.0	28
CSF	RSF + XSF	11,360 CU M/DAY	3.0 MGD	35
CSUI / DAY	CFI x ATC / 100	1,700 SLU/DAY	450,000 SLU/DAY	48
CSUO / DAY	CSF x RSC / 100	1,700 SLU/DAY	450,000 SLU/DAY	35
CSUO / HOUR	CSUO/DAY / 24	71 SLU/HR	18,750 SLU/HR	35
CSDT	CSU / CSUO/HOUR	1.39 HRS	1.40 HRS	35
CFP	100 x CSF / CFO	50.0 %	50.0 %	15
CFP	100 x ATC / (RSC - ATC)	50.0 %	50.0 %	13
RFP	100 x RSF / AFI	47.5 %	47.5 %	15
SAH	(ADT x 24) / (ADT + CSDT)	18 HRS/DAY	18 HRS/DAY	36
XSU	XSF x XSC / 100	57 SLU/DAY	15,000 SLU/DAY	38
FEC	FETSS / MCR	0.0125 %	0.0125 %	38
ESU	CFO x FEC / 100	2.84 SLU/DAY	750 SLU/DAY	38
TXU	XSU + ESU	60 SLU/DAY	15,750 SLU/DAY	38
AGE	TSU / TXU/DAY	6.6 DAYS	6.6 DAYS	38
AAG	AGE x SAH / 24	5 DAYS	5 DAYS	38
CLARIFIER SLUDGE FLOW DEMAND				
CSFD	CSF x (RSC - ATC) / (SSC - ATC)	14,200 CU M/DAY	3.75 MGD	40

* ATC OF 3.0 USED IN THE SSC EXAMPLE.